LISHEP 2011

The Composite Higgs

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Introduction:

Main **Goal** of the **LHC**:

"Unveil the Nature of **EWSB** mechanism"

To achieve this, develop and test hypothetical models

Introduction:

From theory side we assign **different priority** to different New Physics searches:

- Look for a **motivated** scenario
- Prefer **robust** (unavoidable) predictions
- Employ **simple** models for **“portable”** result

Introduction:

The **Elementary** (Standard) **Higgs**

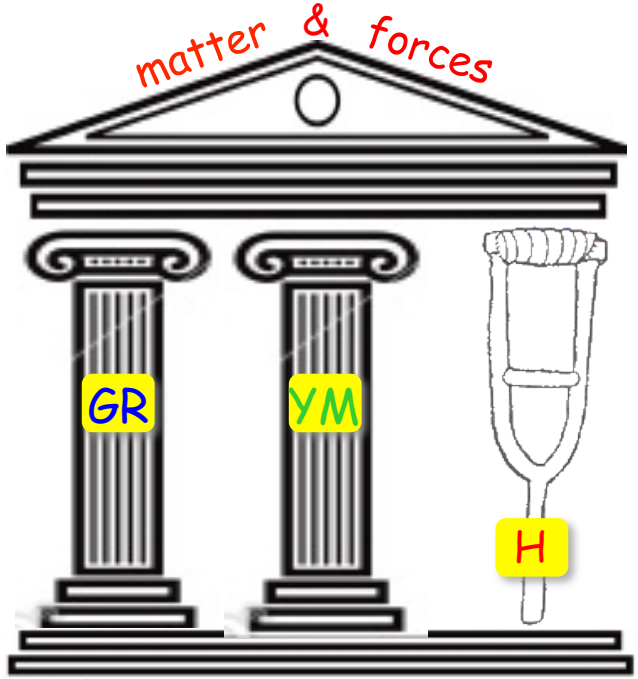
Very well motivated:

- **Minimal** extension of the **EW theory**
- Structural **flavor** protection (**GIM**, or **MFV**)
- Compatible with **EWPT@LEP**
- **Predictive:** technically complete until $\Lambda_{SM} \gg \mathrm{TeV}$

Introduction:

The **Elementary** (Standard) **Higgs**

However, perceived as **provisional** solution:



(from G.Giudice)

- Known scalars are **emergent** (composite) like **pions**, or in **superconductors**
- **Hierarchy Problem:**

$$m_H^2 = \delta m_H^2|_{SM} + \delta m_H^2|_{BSM}$$
$$= c\Lambda_{SM}^2 + \left(m_H^2 - c\Lambda_{SM}^2\right)$$

Introduction:

Question for **LHC**: is there an **Hierarchy Problem ?**

Known **Solutions:**

Weakly coupled:

Supersymmetry:
Exhaustively studied
Soon excluded or found

Strongly coupled:

Technicolor:
Constraints from EWPT

Composite Higgs:
Higgs helps with EWPT

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Composite Higgs

Georgi-Kaplan et al., '84-'85

Higgs = Goldstone Boson

$[G/H = \mathrm{SO}(5)/\mathrm{SO}(4)]$

Composite Higgs

Contino-Pomarol et al., '04-'06

Higgs = Goldstone Boson

$[G/H{=}\mathrm{SO}(5)/\mathrm{SO}(4)]$

Described by a **non-linear sigma-model**:

$$\phi^2 = f^2 \quad \Rightarrow \quad \phi = \left(h_1, h_2, h_3, h_4, f\sqrt{1-\vec{h}^2/f^2} \right)$$

$$\mathcal{L} = \partial_\mu \vec{\phi}^t \partial^\mu \vec{\phi} = \left(1 + Z[v^2/f^2]\right)(\partial h)^2 + h^2/f^2 (\partial h)^2$$

Composite Higgs

Rattazzi et al., hep-ph/0703164

Higgs = Goldstone Boson

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Indirect effects:

A) Corrections to SM:

B) Non-ren. **Couplings**:

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Composite Higgs

arXiv:1002.1011

Higgs = Goldstone Boson

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Indirect effects:

A) Corrections to SM:

$[\mathcal{O}(v^2/f^2) \lesssim 20\%]$

- Higgs Br. Ratios
- Higgs Production

  $gg \to h$

B) Non-ren. **Couplings**:

- In $WW \to hh$
- In $gg \to hh$?

  (vertex $hh\bar{t}t$)

Composite Higgs

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Composite Higgs

arXiv:0709.0007, arXiv:0810.1497

Direct effects: Production of **Resonances**

Heavy Vectors (ρ)

- **EW Neutral** and **Charged**
- **DY** Produced, decay to **t**, **b**, **W/h**
- **Direct bound** from **EWPT**: $m_\rho > 2\,\mathrm{TeV}$
- **Reach:** $\sim 2\,\mathrm{TeV}$ for $100\mathrm{fb}^{-1}$ LHC@14

Composite Higgs

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Composite Higgs

hep-ph/0612015

Direct effects: Production of **Resonances**

Kaluza-Klein Gluons

- **Color Octets**
- **DY** Produced, decay to **top pair**
- **No Direct bound** from **EWPT**
- **Reach:** ~ 4 TeV for 100fb^{-1} LHC@14

Composite Higgs

hep-ph/0612015

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NOT YET SO GOOD

Composite Higgs

Sundrum et al., hep-ph/0612180

The **Top Partners**

Required by **Partial Compositeness**

$$|SM_n\rangle = \cos\varphi_n |\text{elementary}_n\rangle + \sin\varphi_n |\text{composite}_n\rangle \,.$$

New **Colored Fermions**

$$Q = (\mathbf{2},\mathbf{2})_{2/3} = \begin{bmatrix} T & T_{5/3} \\ B & T_{2/3} \end{bmatrix}, \qquad \widetilde{T} = (\mathbf{1},\mathbf{1})_{2/3}\,,$$

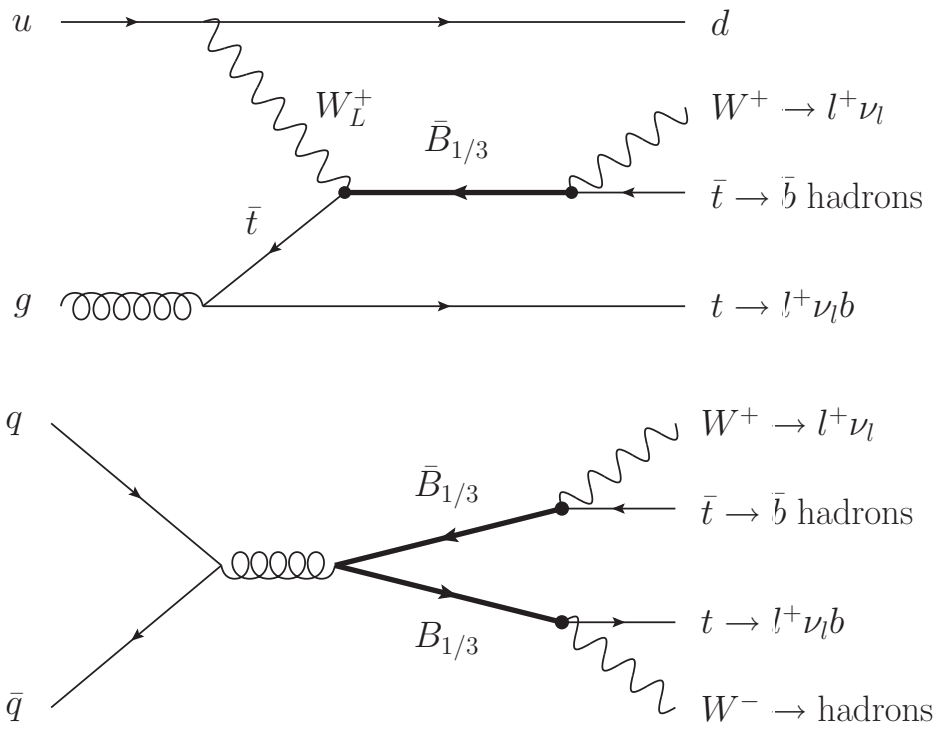
Strongly coupled to **tops**

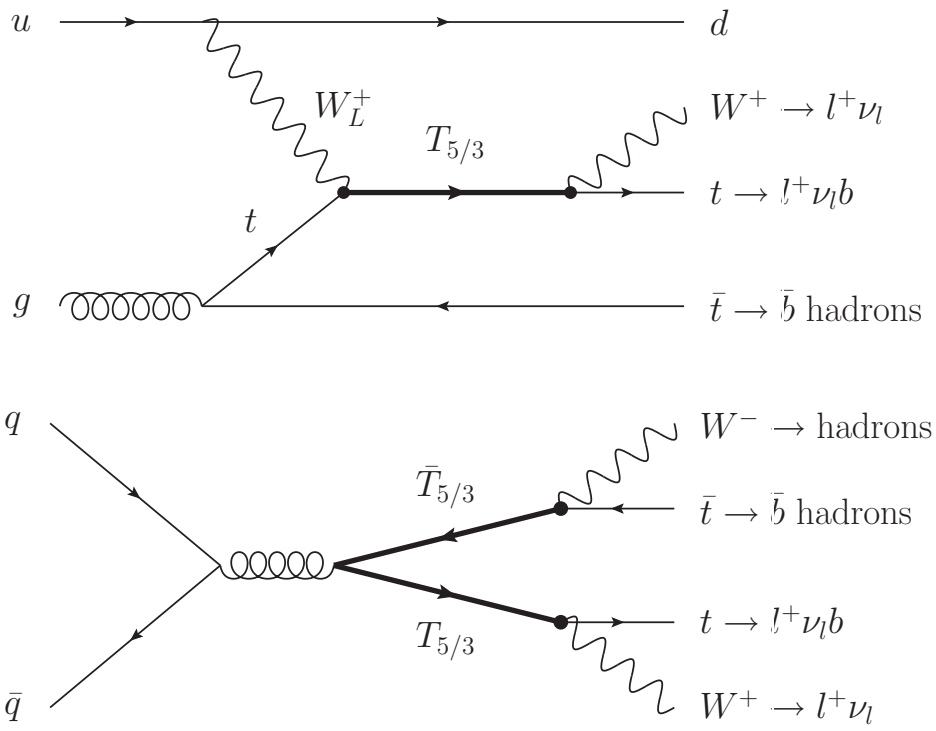
Composite Higgs

arXiv:0801.1679, arXiv:0909.3977

The **Top Partners**

Signal in **Same-Sign Dileptons**



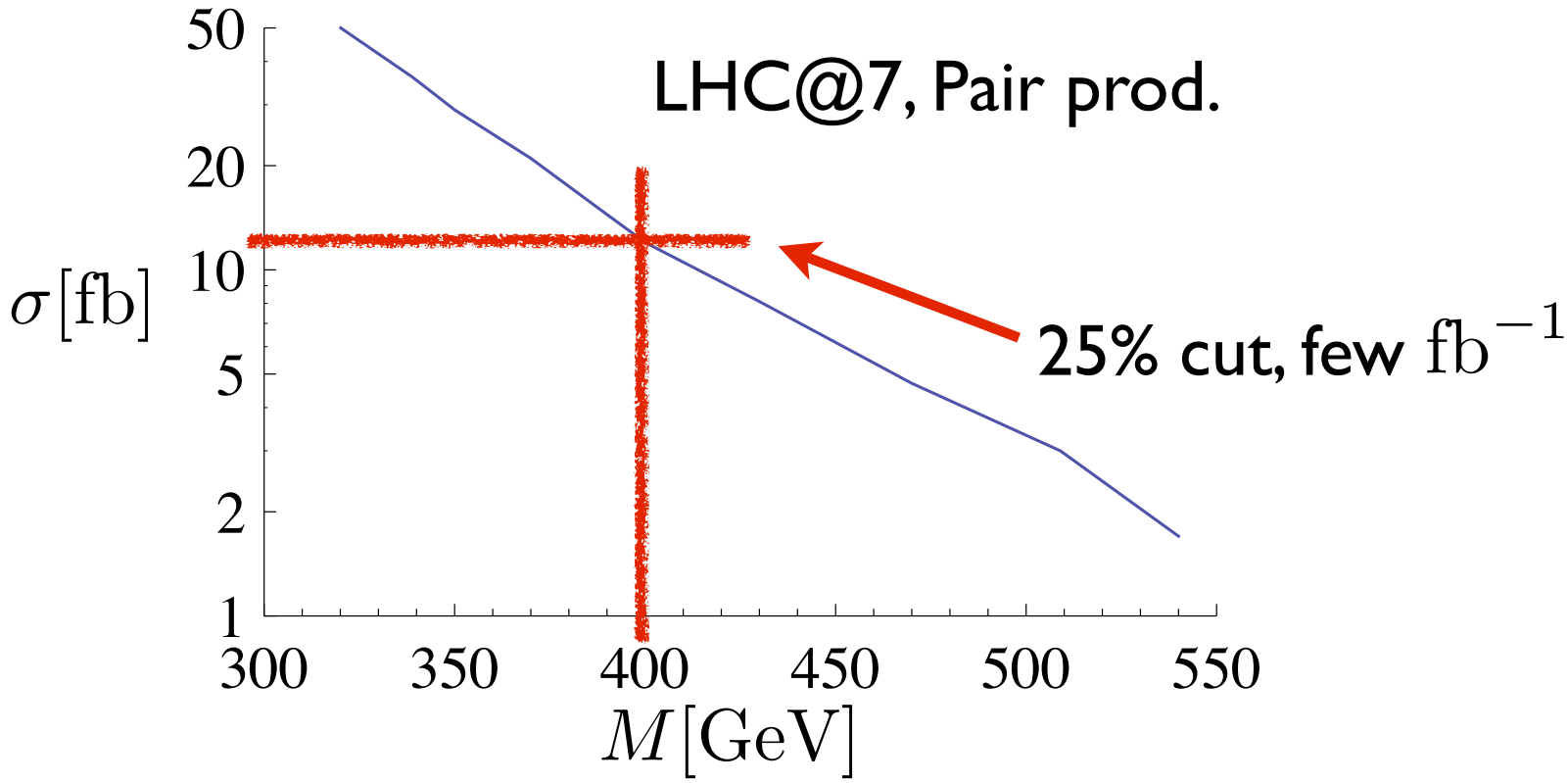


Composite Higgs

The **Top Partners**

Under Investigation:

- Nespolo, Vanini (from **CMS**)
- Gauthier, Etienvre (from **ATLAS**)

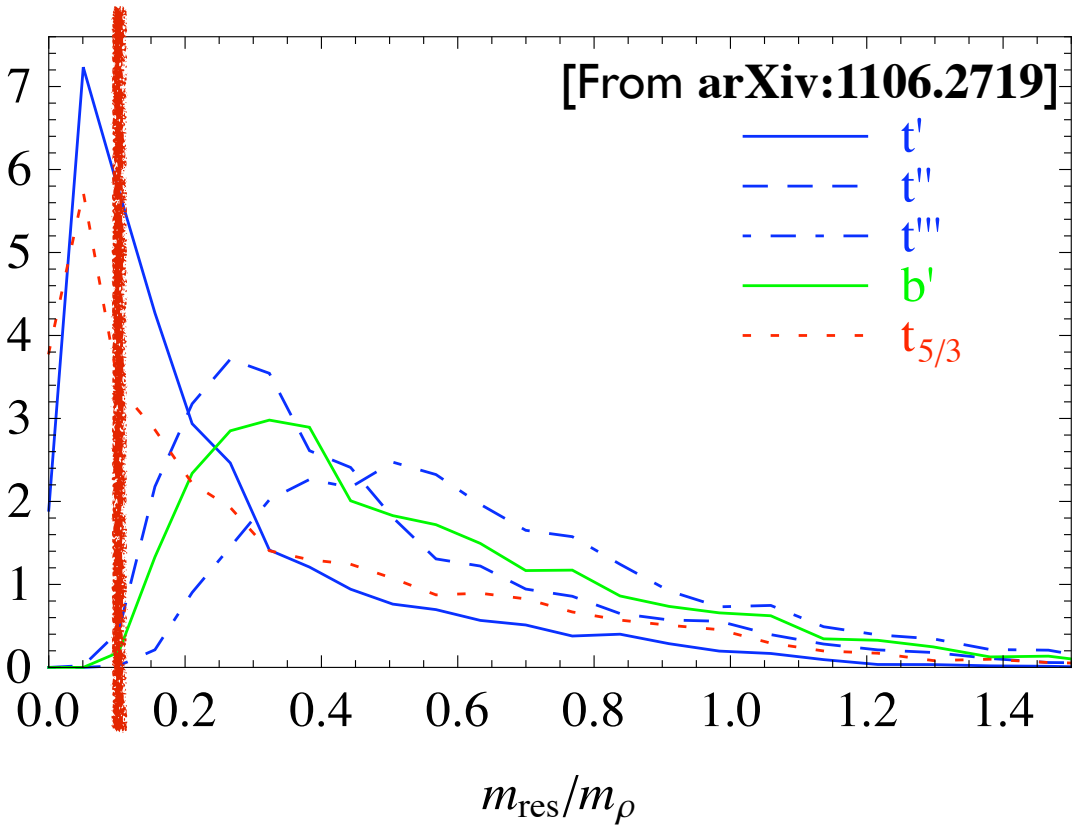


Composite Higgs

hep-ph/0612048

The **Top Partners**

Happen to be **light** in explicit models



Conclusions and Outlook

At the present stage, **top partners** and possibly **KK gluons** are the only visible manifestations of **CH**

Stringent tests of **Higgs Compositeness** are for a more mature stage of **LHC**

But are we ready for a detailed search program ?

Conclusions and Outlook

Historical weakness of **CH** models was lack of concrete calculable incarnations

Problem solved by **Holographic Models in 5d** (**MCHM**, Contino-Pomarol 2004)

Conclusions and Outlook

arXiv:1106.2719

Limitation of **MCHM** is **technical complication**

Discrete Models (DCHM) address this issue (A.W., Panico 2011), soon a complete card for event generator

Goal is provide a **simple** but **complete** "reference" model for searches (analog of the **MSSM** for SUSY)